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THE INTERPRETATION OF TIROS RADIATION DATA FOR PRACTICAL USE IN SYNOPTIC WEATHER ANALYSIS

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SUMMARY

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Radiation data in the 8 to 12 micron atmospheric "window" and 6 to 6.5 micron water-vapor absorption region, acquired from the TIROS III meteorological satellite on July 16, 1961, are used to demonstrate some of the practical applications of satellite radiation data in synoptic weather analysis—looking to the near future when similar data will become available for operational use. These applications include the mapping of horizontal cloud patterns at three different scales from meso- to quasi-global, the derivation of mean relative humidities in the troposphere over the United States, and the inference of vertical cloud structure along a cross section extending from Jamaica to British Columbia.

Each of the applications is discussed in the light of the corresponding conventional surface, upper air, vertical motion, relative humidity, precipitation, and cloud-cover charts. Also, satellite television pictures are used in the discussion of meso- and macro-scale cloud mapping.

In general, a good synoptic correspondence is found between the conventional data and television pictures and the radiation data. Plausible mechanisms to explain several apparent discrepancies between the satellite and the conventional data are presented.

Author

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THE INTERPRETATION OF TIROS RADIATION DATA FOR PRACTICAL USE IN SYNOPTIC WEATHER ANALYSIS

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INTRODUCTION

Since the initial launch of the TIROS I meteorological satellite in April 1960, four satellites of the TIROS series have been used for radiation experiments by the National Aeronautics and Space Administration: TIROS II, III, IV, and VII.[†] In addition to the standard camera systems, these satellites carried a five-channel medium-resolution radiometer which measured the outgoing radiation of the atmosphere-earth system in five different spectral regions.

A comprehensive series of publications already has described the details of the radiometer design, the data evaluation processes, and various results in many fields of atmospheric physics (References 1 through 6). The purpose of this paper is to demonstrate some of the practical uses of satellite-detected radiation data in synoptic weather analysis.

TIROS RADIATION EXPERIMENT

The TIROS scanning radiometer consists of five channels, each channel being sensitive to a certain spectral region of the visible and infrared radiation which is reflected or emitted by the earth's surface and the atmosphere into space. The spectral sensitivities of the channels are as follows:

Channel	Spectral Region (micron)	Purpose
1	6.0 - 6.5	ν_2 fundamental water-vapor band
2	8 - 12	Atmospheric "window"
3	0.2 - 6	Total reflected solar radiation
4	7 - 30	Total outgoing infrared radiation
5	0.55 - 0.75	Response of television camera systems

*On leave from the Institut für Meteorologie und Geophysik der Freien Universität Berlin, Berlin, Germany, as a National Academy of Sciences-National Research Council Research Associate with the National Aeronautics and Space Administration.

[†]Designations: TIROS I-1960 β 2; TIROS II-1960 π 1; TIROS III-1961 ρ 1; TIROS IV-1962 β 1; TIROS VII-1963 24A.

Contrary to the design of the television picture system of the TIROS satellites, the infrared radiation data are not restricted to the daylight portions of the orbits. Thus, with the current system of acquisition stations, radiation data are available for a maximum of 9 out of 14 orbits per day, covering the quasi-globe. For example, the scan limits are approximately 55°N and S for TIROS III, and approximately 65°N and S for TIROS VII. Some examples of the large spectrum of applicability for this type of satellite information will be shown in the following sections. It will become increasingly evident that the TIROS radiation data delineate significant meteorological characteristics of the atmospheric circulation, such as cloud regimes of cyclones and anticyclones, fronts, squall lines, tropical storms, monsoonal clouds, convergence zones, and other important seasonal and diurnal synoptic features.

DERIVATION OF HORIZONTAL PATTERNS OF CLOUDINESS FROM TIROS RADIATION DATA

The radiation maps shown in this study were plotted and analyzed in terms of the basic quantity measured in the laboratory calibration, namely, the equivalent blackbody temperature T_{BB} (°K). The values of T_{BB} should not be interpreted as the temperatures of viewed surfaces (although, for measurements in the 8 to 12 micron window, the difference between the two may be small under certain conditions). A T_{BB} measurement of a given radiometer channel is simply the temperature of a blackbody which, when filling the field of view, would cause the same radiation output as that which results from viewing the generally non-blackbody radiation from the earth and its atmosphere (References 7 and 8).

There are some uncertainties involved in the interpretations of the T_{BB} values. For example, the earth's surface and cloud layers do not emit exactly as a blackbody; and absorption and re-emission by gases in the atmosphere can markedly change the characteristics of outgoing radiation from the underlying surfaces. The radiometer calibration, as well as data conversion procedures, also can inject some uncertainties into the analysis. Diagnostic methods have shown, after applying corrections, that the estimated relative accuracy for TIROS III channels 1, 2, and 4 is $\pm 2^\circ\text{K}$ while the estimated absolute accuracy is $\pm 4^\circ$ to $\pm 8^\circ\text{K}$ up to orbits 118, 875, and 130, respectively, after which the use of the data in terms of absolute measurements becomes questionable (Reference 1). However, considering the complete lack of conventional synoptic data over considerable portions of the earth's atmosphere, the range of radiometer inaccuracy is not of major importance for global or meso-scale synoptic-radiation analyses.

To properly interpret the "window" radiation measurements, the field of view also must be carefully considered. The individual medium-resolution radiometer sensor has an aperture of approximately 5 degrees (between the half-power points) which corresponds to a scan-spot diameter of 40 miles when it scans in the vertical, and an elongated scan spot having an area approximately 10 times as large with a 58-degree-scan nadir angle (Reference 9). Hence, high-scan nadir angle data recorded during each rotation of the satellite (9 to 12 rpm) will have a poorer resolution than low-scan nadir angle data. When a homogeneous overcast cloud layer or clear skies over a sea or land region fill the field of view of the radiometer, a uniform interpretation of the T_{BB}

values, in terms of surface and cloud-top temperatures, can be made. But, if scattered to broken cloud decks of varying transparency are viewed, the radiation originating from the ground and the various cloud layers contribute to the integrated intensity detected by the satellite and make the interpretation of the measurement very difficult (Reference 10). Other means, such as conventional surface and upper air observations, in-flight reports, and satellite television pictures, must be used to resolve the detailed horizontal and vertical cloud structure.

The two short-wave channels (3 and 5) can be used to detect the presence of highly reflective clouds, provided the earth's surface below provides sufficient contrast in reflectance. Areas covered by snow, ice, light-colored earth, or desert sand can lead to misinterpretation of cloud fields. Use of the "solar" channels is restricted to the daylight portion of the earth in a manner similar to the television camera system; and the strength of reflected short-wave radiation becomes marginal at low solar elevation angles during sunset, sunrise, and the winter season at high latitudes.

Channel 2, which is not dependent on solar illumination and is least effected by atmospheric absorption, is best suited for the detection of cloud cover if corrections for instrumental degradation, small residual water vapor, and ozone are applied (References 1 and 6).

Meso-Scale Clouds and Radiation Patterns

The capability of using the TIROS radiation data for a detailed cloud analysis is demonstrated in Figures 1 and 2. A cloud system at 10°N, 40°W on July 16, 1961, which was later identified as the early stage of Hurricane Anna, was selected for the analysis (Reference 11).

Figure 1 shows the channel 2 radiation analysis for this storm. These data were acquired in the single open scanning mode and hence are located with greater accuracy than data acquired in either of the other two scanning modes, namely, the alternating open and closed scanning modes (Reference 12). Each scan spot (cross mark) was hand-plotted from a computer listing. The computer listing contains the geographical location of each scan spot, the scan nadir angle, the azimuth angles, and simultaneous readings for all five radiation channels (Reference 13).

The radiation analysis shown in Figure 1 was superimposed on a TIROS television picture of the same storm (Figure 2). Good agreement was found between the television picture and the radiation field, even out to the outer fringes of the photograph. An equivalent blackbody temperature difference of more than 50°K was indicated between the highest cloud tops (230°K) and the partly cloudy ocean area (282°K). By use of the Dakar, Senegal radiosonde sounding for 0000 GMT, July 16, 1961 (Reference 14), the 230°K T_{BB} value related to an "effective radiation height" of approximately 250 mb (35,000 ft). The *effective radiation height* is defined as that height in the atmosphere where the ambient temperature equals the equivalent blackbody temperature T_{BB} .

Several examples employing a detailed hand analysis of Hurricane Anna on July 23, 1961, are found in References 15 and 16.

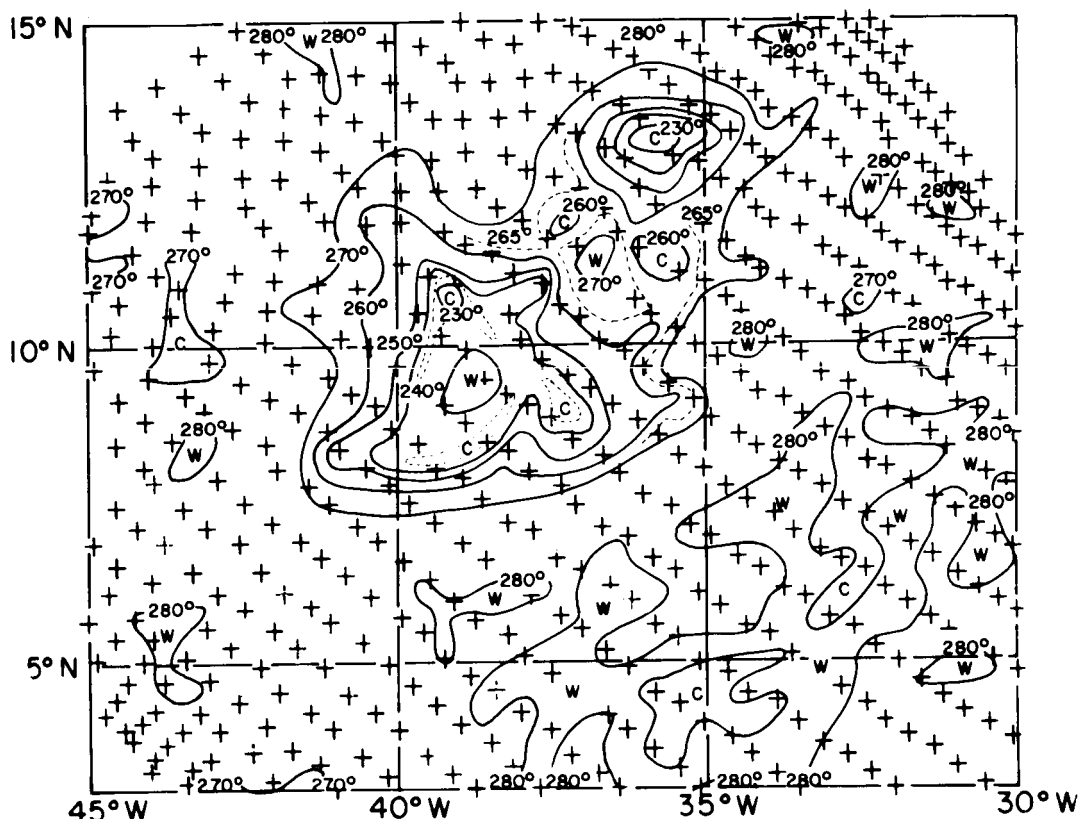


Figure 1—Analysis of channel 2 radiation data of the early stage of Hurricane Anna, July 16, 1961, (open mode data only) hand-plotted from listings.

Macro-Scale Clouds and Radiation Patterns

Besides the detailed structure of meso-scale cloud systems, the general distribution of cloudiness in the macro-scale is of vital interest to the synoptic meteorologist. The high correlation between the outgoing radiation within the water vapor window and cloudiness (References 10, 16, 17, and 18) represents a useful application of radiation data provided by the TIROS satellite. An example will be given in this section.

Figures 3 and 4 show the surface synoptic chart and the corresponding 500-mb upper-air chart analyzed by the National Meteorological Center, U. S. Weather Bureau, for 1200 GMT, July 16, 1961. The general weather pattern over the United States is characterized by an upper ridge and a weak surface high over the western states, a thermal surface low over the southwest, and an upper trough over the Mississippi Valley with well-developed thunderstorm and shower activity extending NE/SW from Maine to Texas. A second area of cyclonic activity is indicated by a frontal zone along the northwestern border states.

The observed surface cloud patterns for 1200 GMT are shown in the conventional nephanalysis chart (Figure 5). The broad region of cloudiness over the southeastern United States is confirmed

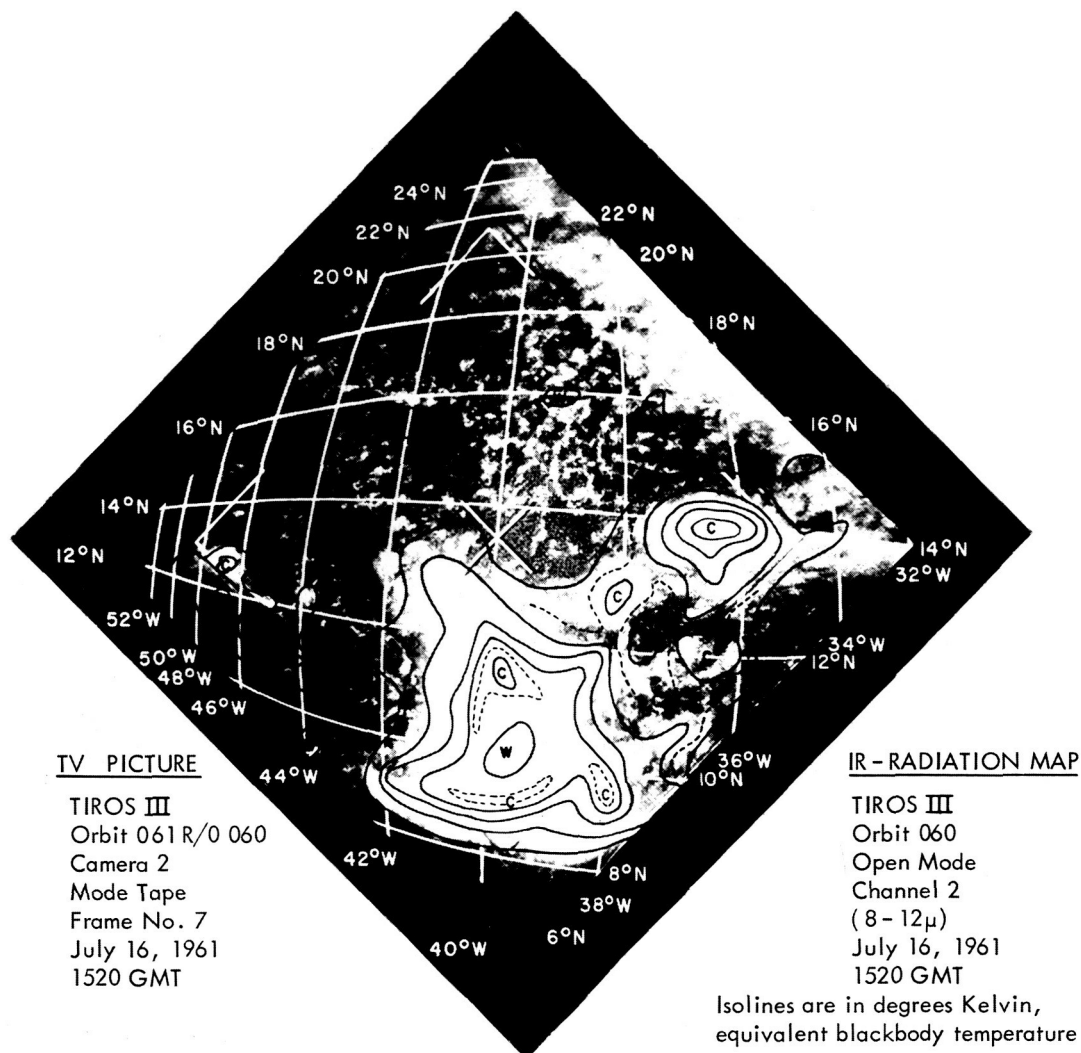


Figure 2—Composite analysis of channel 2 radiation data (listings) and a gridded television picture of the early stage of Hurricane Anna.

by a mosaic of television pictures taken during orbit 61 (Figure 6). However, the synoptic explanation for the distinctive weather features over Louisiana, Mississippi, Alabama, Tennessee, and Kentucky was singularly lacking in the surface analysis.

The channel 2 radiation analysis for orbits 57, 58, and 60 over the United States was drawn (Figure 7). This computer-produced map was printed on a 1:10 million scale, with a 40-degree-scan nadir angle limitation. An average $+4^{\circ}\text{K}$ correction was applied to channel-2 T_{BB} values for instrumental degradation (Reference 1).

The 230° to 270°K isolines outline high-reaching clouds over the Appalachian Mountains and lower Mississippi Valley and a broad cloudy region along the northwest and northcentral United States border, southwestern Texas, and the west coast of Florida.

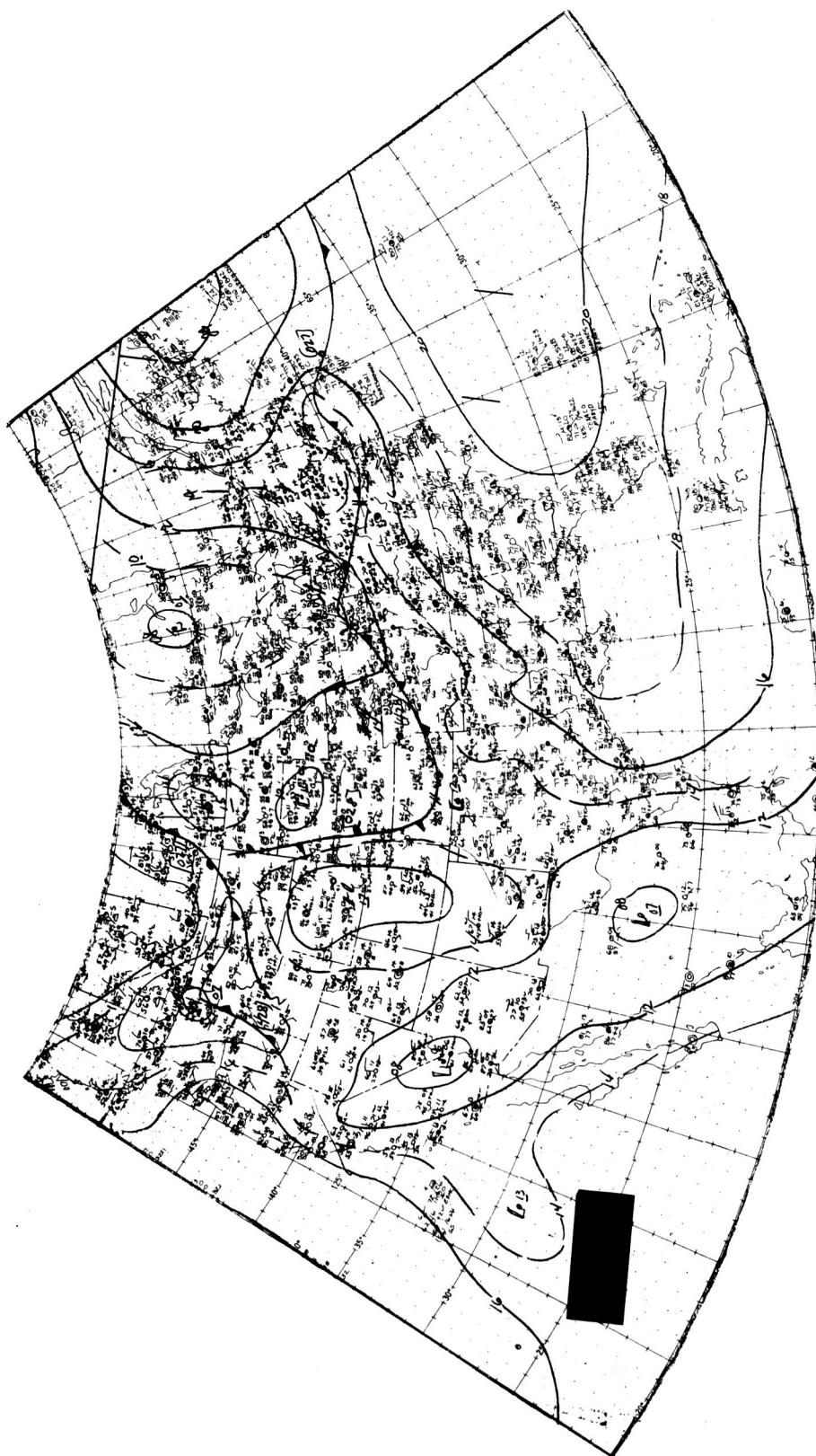


Figure 3—Surface synoptic chart at 1200 GMT, July 16, 1961, over the United States (National Meteorological Center, U. S. Weather Bureau).

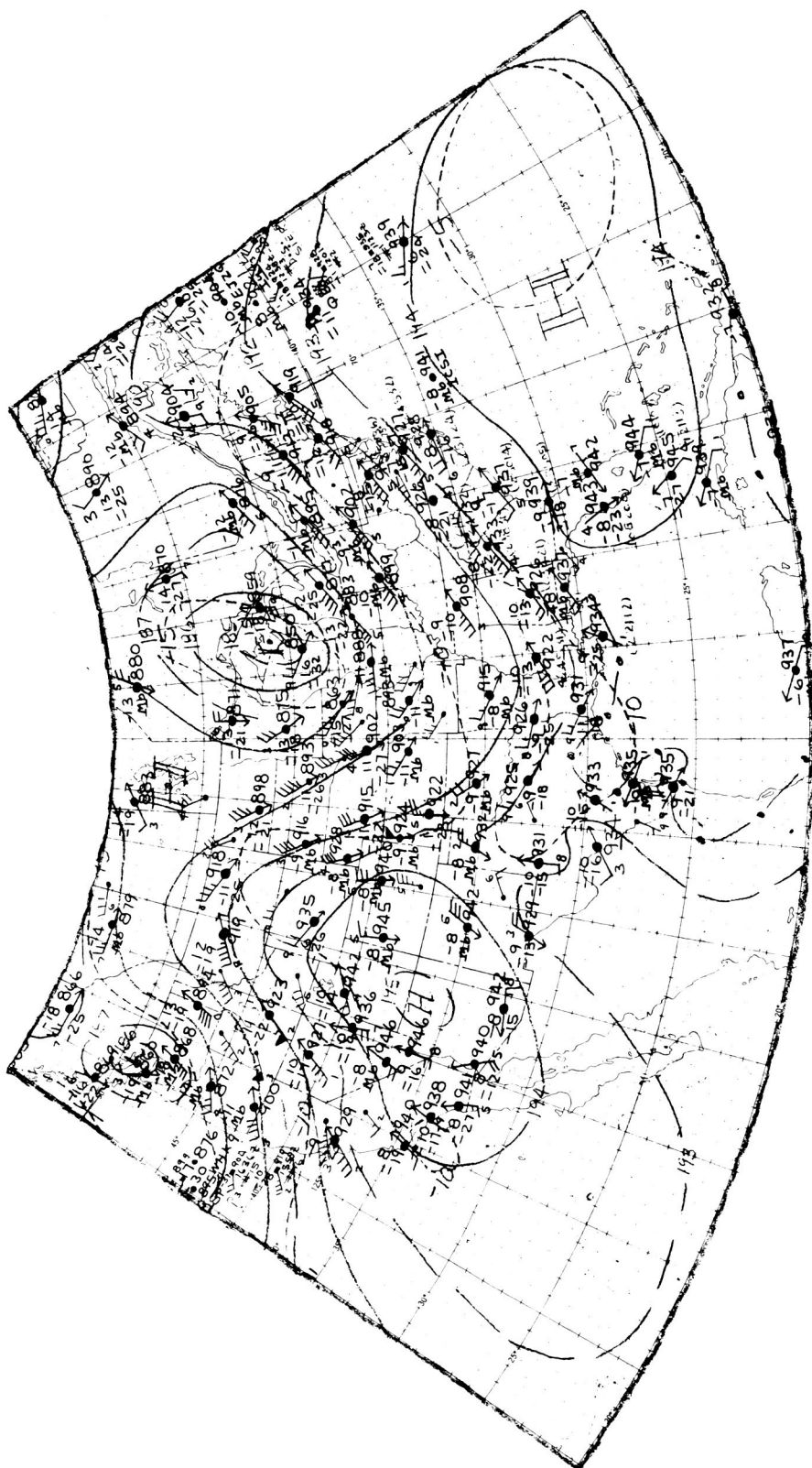


Figure 4—500-mb constant pressure chart over the United States at 1200 GMT, July 16, 1961.

Figure 5—Conventional cloud analysis over the United States at 1200 GMT, July 16, 1961.



Figure 6—Mosaic and nephanalysis of TIROS III television pictures over the United States recorded during orbit 61 at 1655 GMT, July 16, 1961.

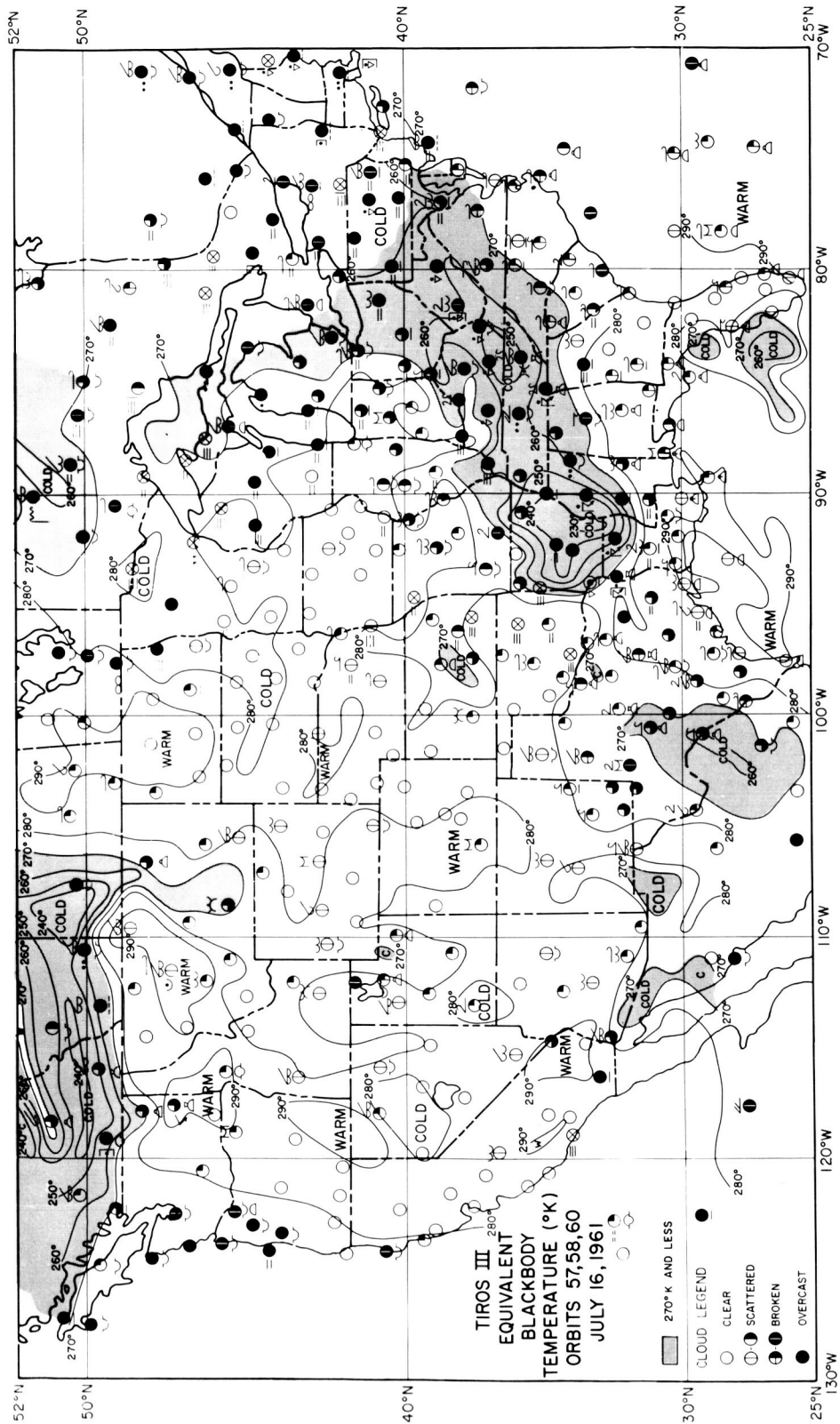


Figure 7—Channel 2 radiation analysis (T_{BB} ; °K) over the United States recorded during orbits 57, 58, and 60 on July 16, 1961, from 1000 GMT to 1500 GMT.

The 280° to 290°K isolines are associated with the clear to scattered clouds in the weak surface high and thermal surface low pressure regions over the central, southwest, and Gulf Coast states. Low-lying stratus and stratocumulus cloud decks over Indiana, Illinois, Michigan, Wisconsin, and Minnesota and the scattered swelling cumulus and cumulonimbus clouds over central Texas occur within regions dominated by T_{BB} values of 270° to 280°K.

Based on this TIROS radiation analysis (Figure 7), the mosaic of TIROS television pictures (Figure 6), and conventional cloud nephelanalysis (Figure 5), a revised surface analysis was prepared (Figure 8).

A cold front, in the state of frontolysis, was drawn in over Ohio, Kentucky, Tennessee, and Arkansas. A prefrontal squall line was shown, extending from Virginia through Tennessee, Alabama, Mississippi to Texas. An instability line, off the east coast, was drawn crossing the north end of Florida (cumulonimbus activity) and merged with an easterly wave over western Cuba.

The cloudiness over northwest Florida, as shown in the television mosaic (Figure 6), is in good agreement with the channel 2 radiation data (Figure 7) with only a slight displacement, which was caused by a 3- to 6-hour data-recording time differential.

DERIVATION OF TROPOSPHERIC MEAN RELATIVE HUMIDITY FROM TIROS RADIATION DATA

Channel 1 of the medium-resolution scanning radiometer is spectrally sensitive to emission within the fundamental water-vapor band (6.0 to 6.5 micron). F. Möller has developed a method of interpreting the radiation detected within this region in combination with channel 2, as a measure of the mean vertical relative humidity of the troposphere (References 17, 18, and 19).

This method, which assumes a model atmosphere with a range of constant relative humidity in the vertical, provides an estimate of the mean relative humidity ($\pm 15\%$) for homogeneous overcast or clear sky condition (Reference 17) and tends to overestimate this parameter for nonhomogeneous scattered to broken cloud conditions.*

The following sections will describe an evaluation of the Möller technique over the United States on July 16, 1961, which complements an analysis performed over Europe on July 15, 1961, (Reference 17).

Method of Analysis

The TIROS III evaluation diagram for conversion of channel 1 and channel 2 to tropospheric mean relative humidity is presented in Figure 9. This diagram was constructed by W. R. Bandeen (Goddard Space Flight Center) for a tropical model atmosphere and was presented to the Workshop on the Uses of Satellite Data in Tropical Meteorology, Tallahassee, Florida, in February 1963. Möller has shown that evaluation diagrams for various atmospheres are essentially equivalent

*W. R. Bandeen, Private Correspondence, June 1964.

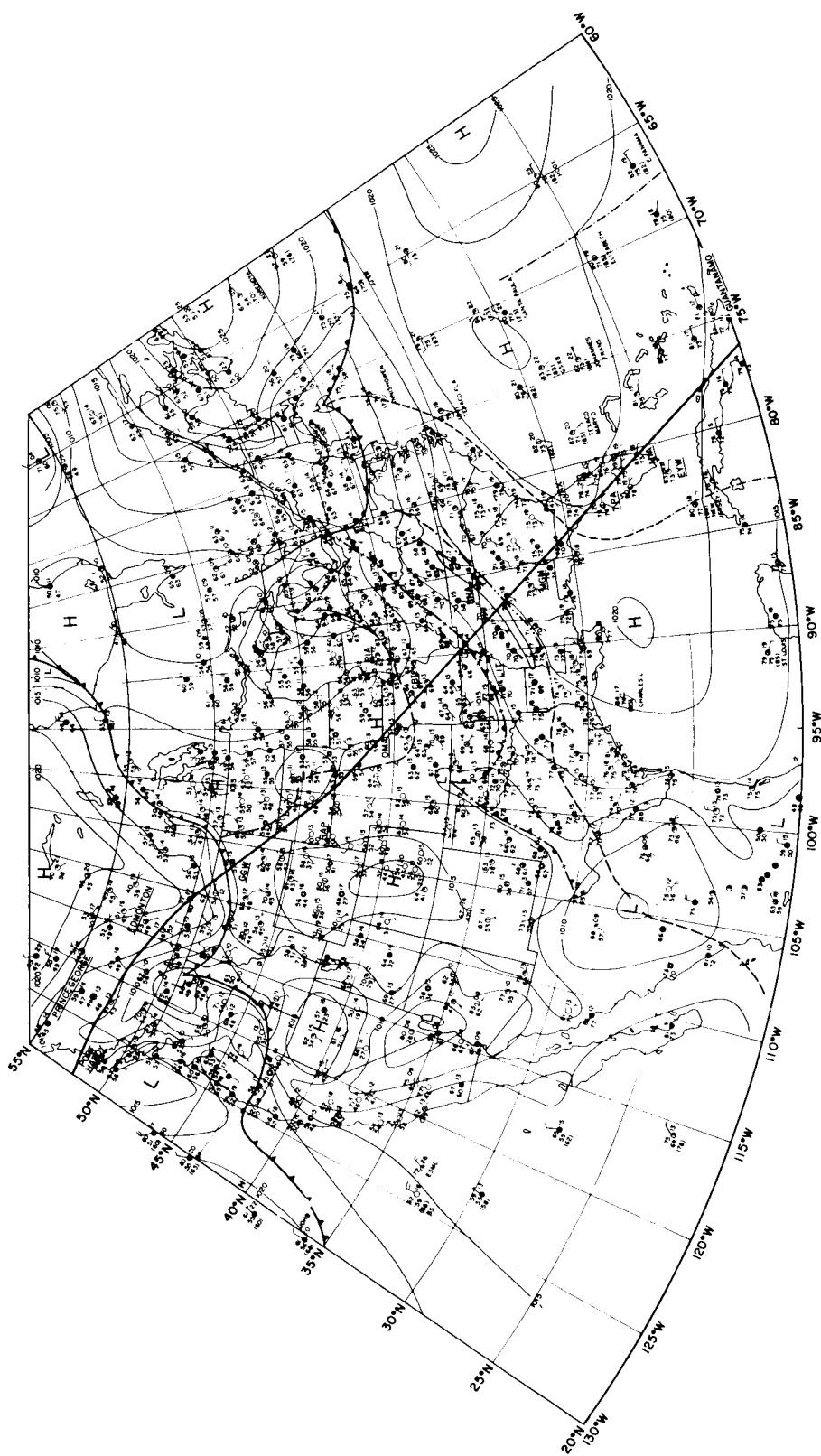


Figure 8—Revised surface analysis over the United States at 1200 GMT, July 16, 1961 (diagonal line indicates path of vertical cross section in Figure 17).

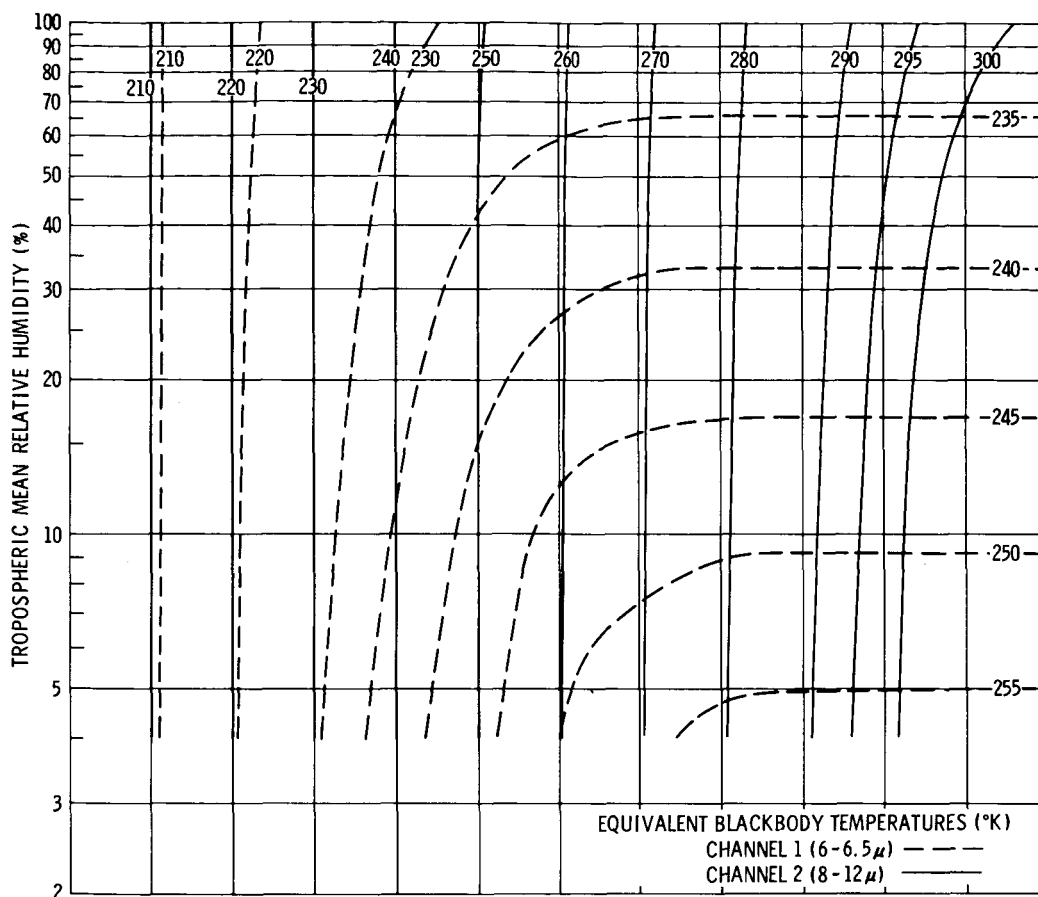


Figure 9—TIROS III evaluation diagram for conversion of channel-1 and channel-2 T_{BB} data to tropospheric mean relative humidity (%). For a pair of simultaneous channel 2 and channel 1 values, the mean relative humidity is determined by their intersection. For example, for channel 2 (260° K) and channel 1 (235° K), the mean relative humidity is 60 percent.

(Reference 17), and it was deemed satisfactory for the purpose of this paper to utilize this diagram for middle latitudes as well. Since the determination of mean relative humidity becomes extremely inaccurate below 230° K, it was assumed that, for values below 230°, the relative humidity was >90% (Figure 9). Corrections for degradation and scan nadir angle were made in accordance with the TIROS III Radiation Data Users' Manual Supplement (Reference 1) and nomograms given by Möller and Raschke (Reference 17).

The channel 1 and 2 grid print maps for orbits 57, 58, and 60 were computer-produced on a 1:10 million scale (composite) with a 40-degree-scan nadir angle limitation. The 41- to 58-degree-scan nadir angle data were used where data gaps existed in the 40-degree data. For a discussion of mapping scales and computer processing technique, see Reference 12.

Figure 10 presents the final analysis of the satellite-derived mean relative humidity for July 16, 1961. Values of 70 percent and greater are shown in dark gray shading, 41 to 69 percent are enclosed in white, and 40 percent and less are shown in lighter gray shading.

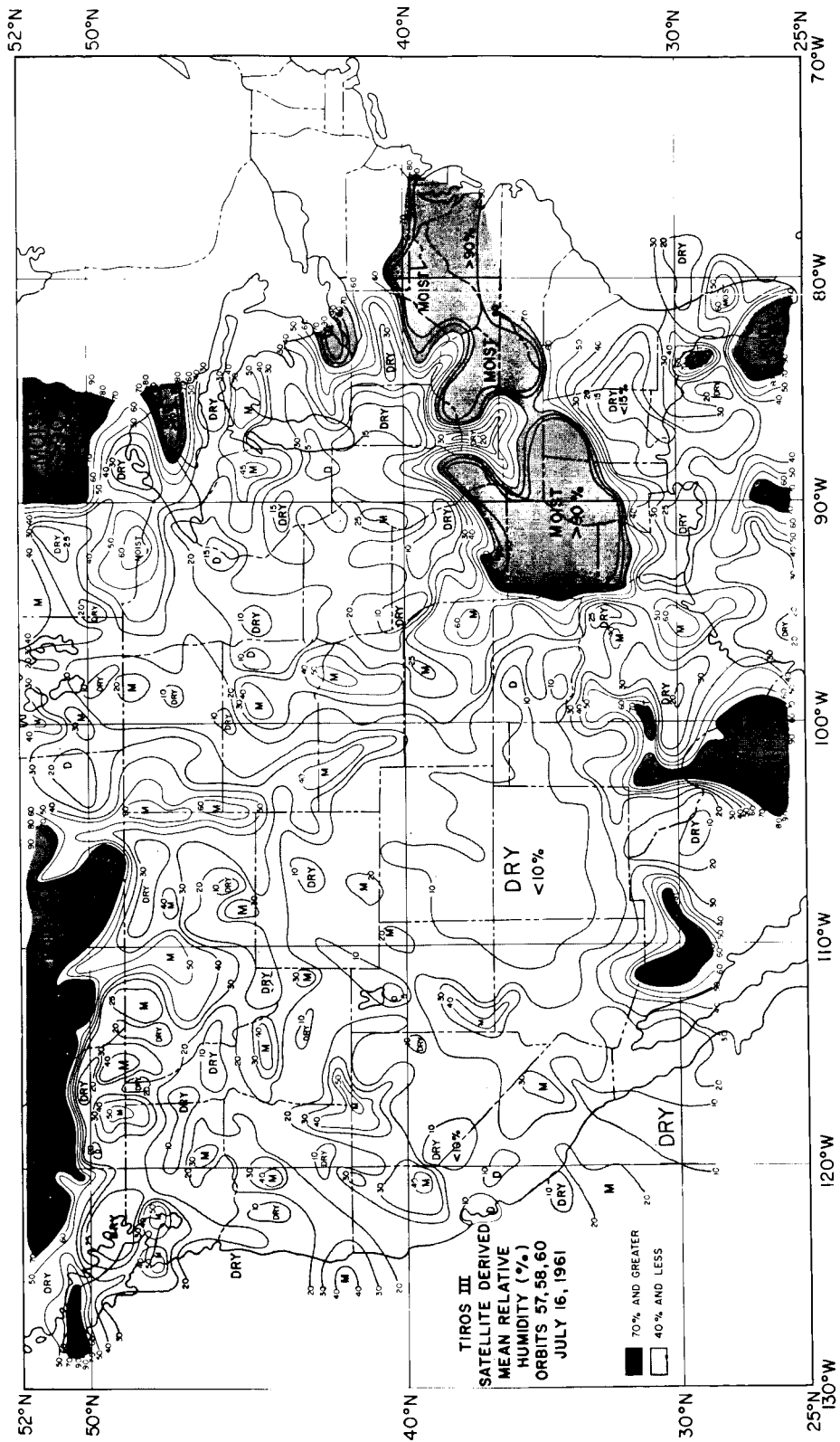


Figure 10—Analysis of satellite-derived mean relative humidity (%) for orbits 57, 58, and 60 on July 16, 1961.

Comparison with Conventional Moisture Patterns

Figures 11, 12, and 13 show the moisture charts for the 300-, 400-, and 500-mb level at 1200 GMT on July 16, 1961, as drawn from U. S. Weather Bureau radiosonde data (Reference 14).

These conventional middle and upper tropospheric moisture charts and the satellite-derived moisture charts (Figure 10) show good agreement in outlining large regions of dryness (<20% R. H.) over the central and western two-thirds of the United States. Two dry tongues, which were oriented N/S through central Texas and NE/SW from the Gulf states to the Carolines, are shown in both types of data. A third dry tongue over western Texas, within the satellite-derived data, does not occur in the conventional analysis but might be suggested within that area of sparse radiosonde data.

The moist region (70% and greater R. H.) in Figure 10 relates best to the integrated radiative contribution of the 300-, 400-, and 500-mb moisture levels. The horizontal and vertical pattern of the moist high clouds over the cold front and the prefrontal squall line, discussed previously, were confirmed with minor variations by the conventional and satellite-derived moisture analyses.

Figure 14 presents an analysis of the U. S. Weather Bureau (National Meteorological Center) mean relative humidity data for the 1000- to 500-mb layer for 1200 GMT. This chart shows the large dry and moist regions described above and, in addition, a well-defined moist tongue over Minnesota, Wisconsin, Michigan, and the Great Lakes.

The satellite measurements would not be expected to be affected by the water-vapor content in the layers below 500 mb, as the atmosphere is largely opaque in the 6 to 6.5 micron region in these layers (Reference 7). Hence, the low-level moisture shown in Figure 14 does not contribute to the satellite derivation of mean relative humidity (Figure 10).

The preliminary moisture analysis presented above has indicated that the TIROS radiation data are capable of providing a gross picture of the upper tropospheric moisture patterns. Further work is required, in view of the problem of instrumental degradation and the assumption of constant relative humidity in the vertical (Reference 17).

Comparison with Vertical Motion Fields

Figure 15 shows the U. S. Weather Bureau vertical motion chart at the 650-mb level for 1200 GMT, July 16, 1961. The following are some interrelations between Figure 15 and Figures 7, 8, 10, 11, 12, 13, 14, and 16 which are of interest:

1. The positive values (upward motion) of +0.1 to +0.9 cm/sec, extending from central Texas to eastern Ohio, overlie the cloud layers of the cold front and squall lines (Figures 7 and 8), areas of high moisture content aloft (Figures 10 through 14), and major precipitation zones (Figure 16).

Figure 11—Analysis of conventional 300-mb relative humidity (%) at 1200 GMT, July 16, 1961, over the United States.

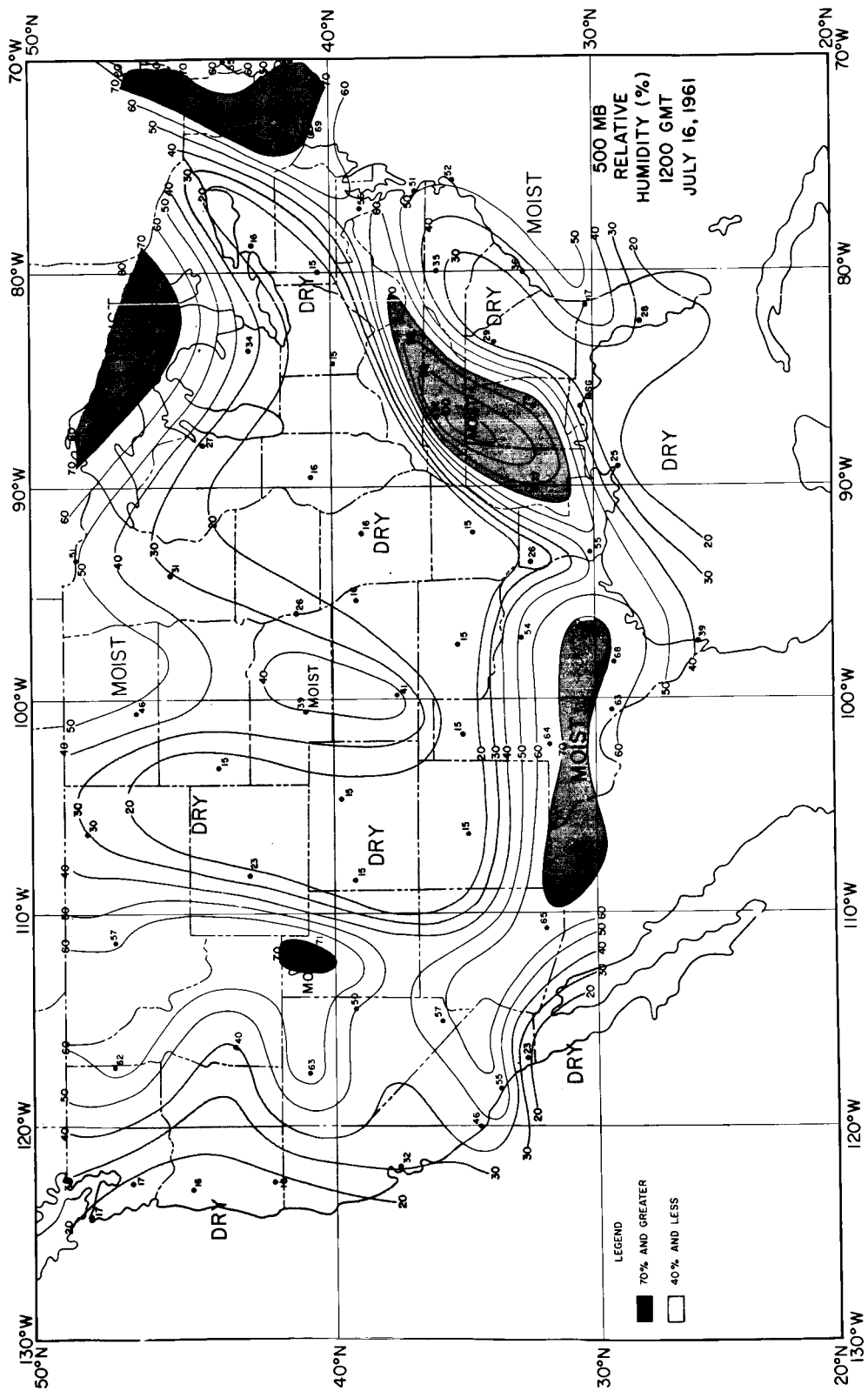


Figure 13—Analysis of conventional 500-mb relative humidity (%) at 1200 GMT, July 16, 1961, over the United States.

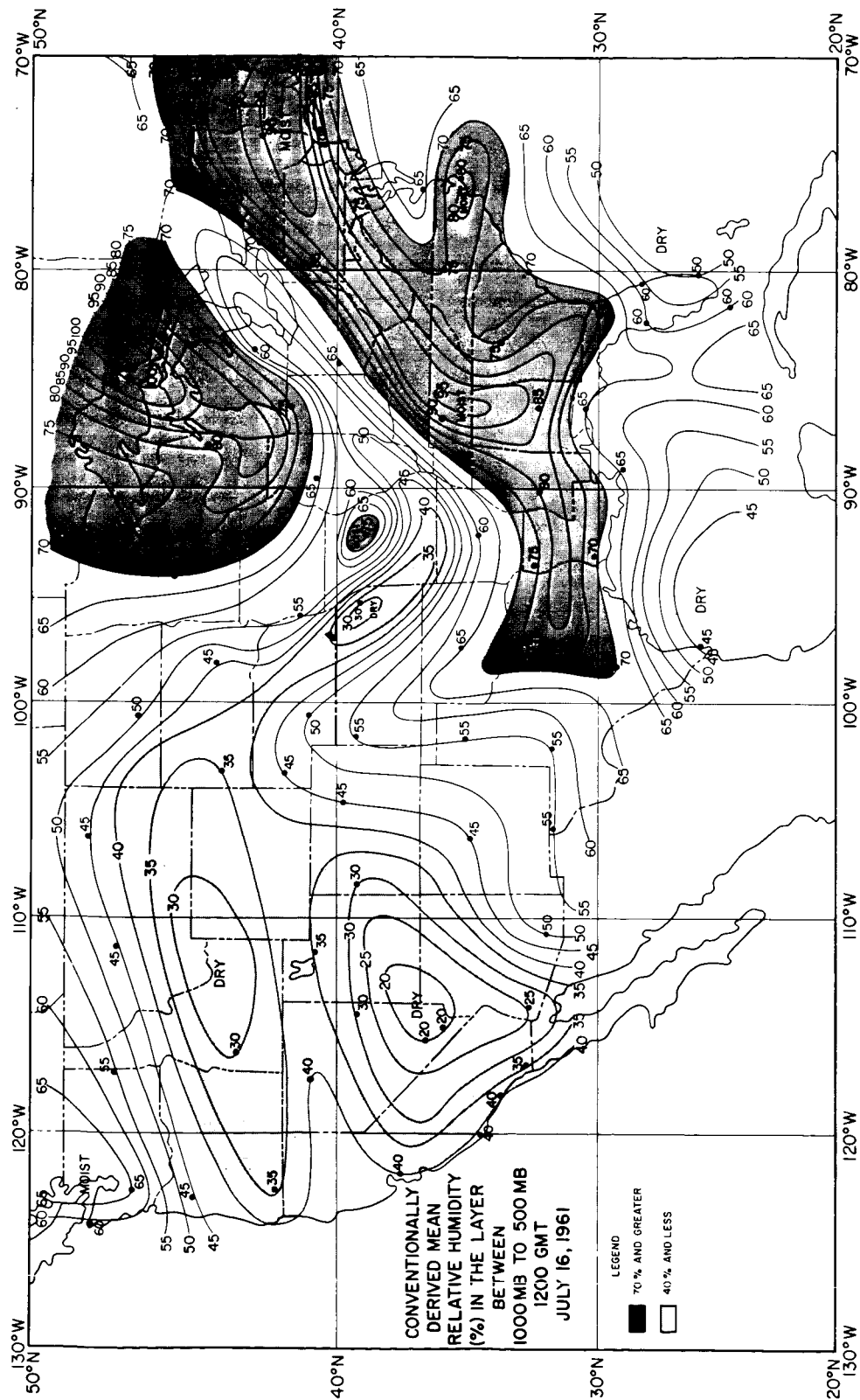


Figure 14—Analysis of conventional 1000-mb to 500-mb mean relative humidity (%) at 1200 GMT, July 16, 1961, over the United States.

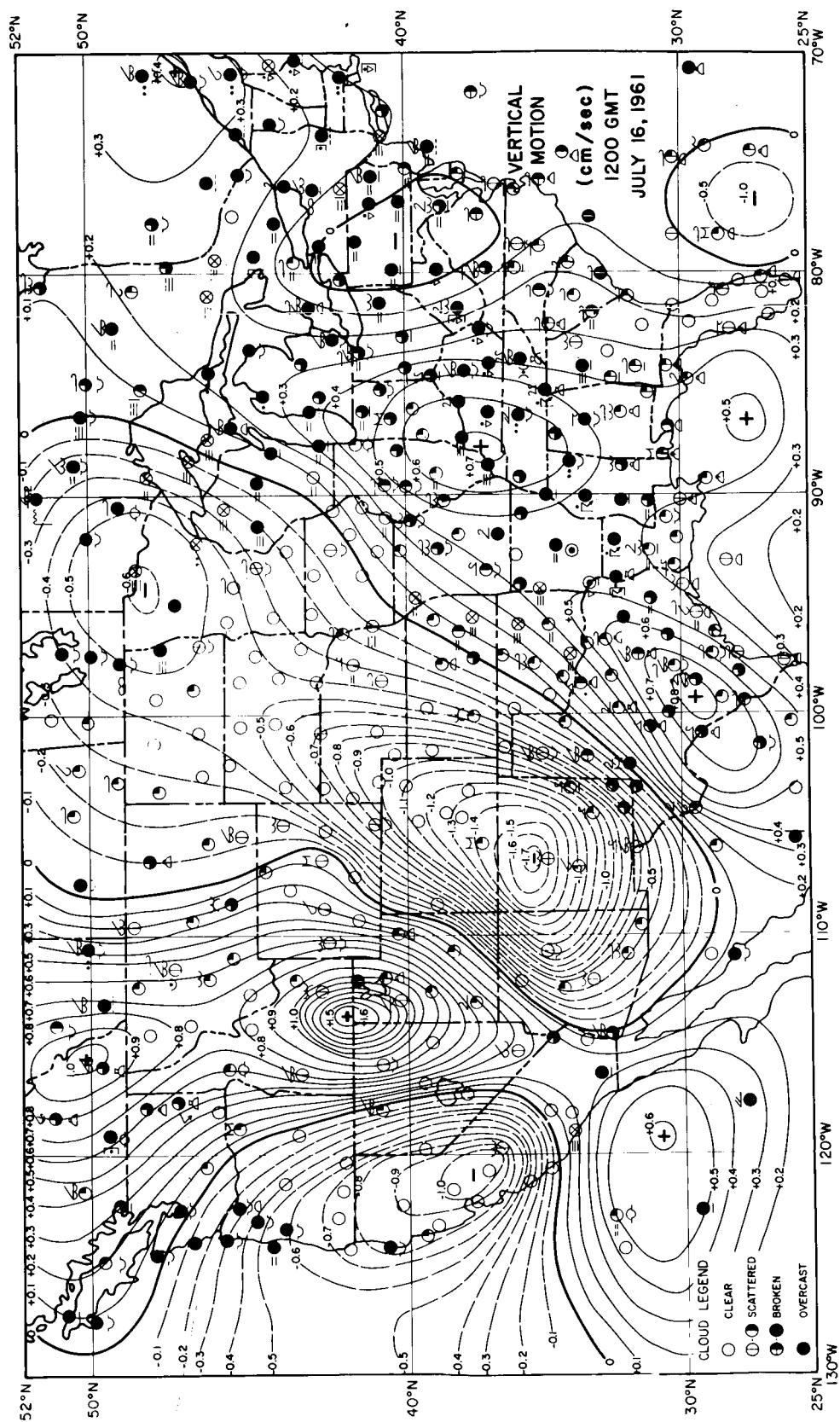


Figure 15—Analysis of vertical motion (650-mb level) in cm/sec at 1200 GMT, July 16, 1961.

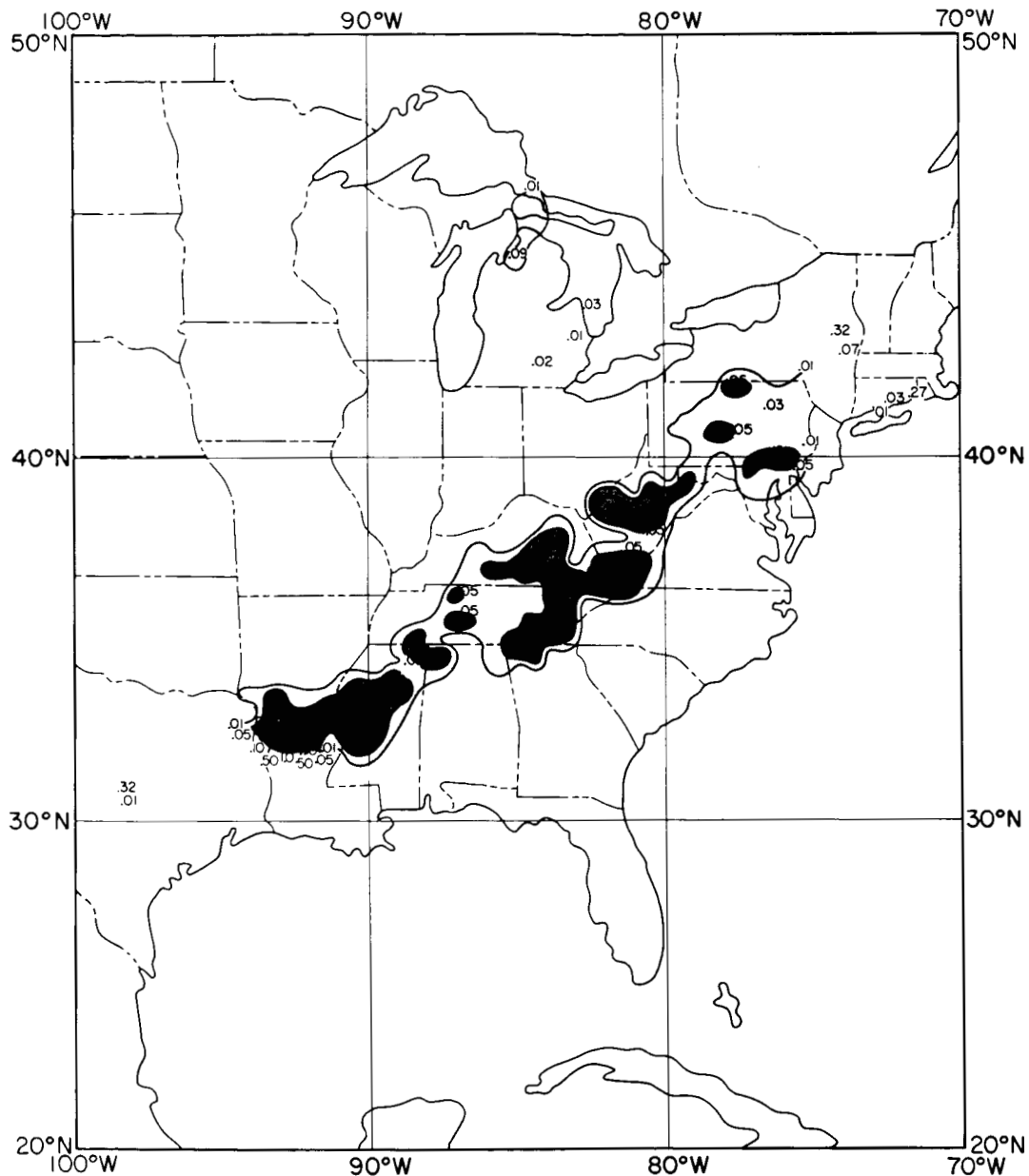


Figure 16—Analysis of precipitation amounts (inches) at 1200 GMT (± 1 hr), July 16, 1961, over the United States.

2. The negative values (downward motion) of -0.6 to -1.7 cm/sec over Arizona and extending from New Mexico northeastward to Minnesota and of -0.1 to -1.0 cm/sec over California, Oregon, and Nevada generally coincide with clear to scattered clouds or low-level cloud decks with dry air aloft. An area of subsidence overlies the 1000- to 500-mb moist tongue over Minnesota, Iowa, and Wisconsin—as previously described in the section on page 15.

When dry air overlies areas of upward motion—such as over southern Idaho, eastern Nevada and Utah, eastcentral Texas and Georgia—a weakening of the cumuloform-type cloud activity was noted.

A qualitative estimate of the large-scale positive and negative vertical motion field could be made from Figure 10 if the generalized relation between ascending motion, saturated air aloft, deep vertical cloudiness, and precipitation—on the one hand—and descending motion, dry air aloft, and suppressed vertical cloudiness on the other were used as a basis (References 20, 21, and 22).

DERIVATION OF VERTICAL CLOUD STRUCTURE FROM TIROS RADIATION DATA

As already indicated in the section on macro-scale clouds, the TIROS channel 2 (8 to 12 micron) data, when converted into equivalent blackbody temperature T_{BB} , may be interpreted to some extent as cloud-top heights. By use of local radiosonde data, the derived T_{BB} value may be located easily in the vertical by means of the vertical temperature profile. In remote areas, however, climatological mean soundings certainly may be used as a first approximation.

The correlation between conventional cloud information and satellite radiation data can be demonstrated by the vertical cross section in Figure 17. This cross section extends from Kingston, Jamaica, northwestward across the United States to Annette Island, Alaska, on June 16, 1961, (see Figure 8) and is based on conventional upper air data at 1200 GMT (Reference 14). The temperature field ($^{\circ}\text{C}$) including discontinuity lines from a squall line, frontal, and tropopause positions was presented. The humidity field was plotted and analyzed by means of temperature-dewpoint differences, as reported in the radiosonde data (Reference 14). In a more schematic manner, the probable cloud distribution was drawn for temperature-dewpoint differences of 3°C or less and from conventional surface and pilot weather reports.

The most apparent features within the cross section (Figure 17) are the prefrontal squall line over northern Alabama, the cold front over northwestern Tennessee, the cold front over Montana, and their corresponding heavy cloud systems—reported by surface observations as well as being derivable from the radiosonde humidity information. Included in this cross section is a heavy solid line with small open circles, which indicates the effective radiation height of channel 2, orbits 56, 57, 58, and 60 on July 16, 1961. The circles give the actual values of T_{BB} exactly along the base line of the cross section. The full dots represent the corresponding values over the radiosonde station location. A larger discrepancy between both values occurs only with regard to Little Rock, Arkansas, as the cross section passes the cold front just in a portion of weakest intensity (see Figures 5 and 8) of cloud development, while much higher reaching clouds are reported in the area surrounding the radiosonde station. The relative dryness indicated by the Little Rock radiosonde measurement may be interpreted as having occurred between several high-reaching cloud cells rather than within the most intense frontal cloud system. Therefore, the schematic indication of the frontal clouds was drawn up to the effective radiation height determined by the satellite measurement.

It should be noted that, while the cross section is valid for 1200Z, the satellite data were recovered from approximately 0800 GMT (for orbit 56 over Cuba) to 1500 GMT (for orbit 60 along the U. S. - Canadian border). Thus, for the central portion of the section—roughly between Tennessee and South Dakota—the conventional and satellite data are quasi-synoptic, and hence some deviations between conventional and satellite data are apparent. Therefore, to make the cross section representative for the area rather than for a single spot of the frontal system, the cloud system of the cold front over Little Rock was drawn in to approximately 22,000 feet. The squall line and cold frontal cloud decks which were primarily based on the humidity profiles over Nashville, Tennessee, and Glasgow, Montana, were found to be in good agreement with the TIROS effective radiation heights.

Northwest of Edmonton—in an area where various cloud layers of stratocumulus, altocumulus, and cirrus were reported—the effective radiation heights appeared between the cirrus clouds at 350 mb and the cloud decks which extended from the surface to 500 mb. The characteristics of the channel 2 emission from scattered to broken cirrus clouds have been discussed previously by Fritz and Winston (Reference 10) and Rao and Winston (Reference 23).

In the clear area around Rapid City, North Dakota, the indicated T_{BB} values of 7.5°C differ from the 20°C shelter temperature. In this case, the thin cloud or moist layer at 650 mb is the primary cause of the temperature difference, although ozone absorption and/or possibly particulate matter near the tropopause at about 13 km also can act to decrease the channel-2 T_{BB} temperature (Reference 23).

QUASI-GLOBAL-SCALE CLOUD DISTRIBUTION

The spectrum of applicability of the TIROS radiation data extends from the meso-scale to the quasi-global scale. Figure 18 is the worldwide synoptic-radiation analysis on July 16, 1961, in which synoptic information from world weather centrals was utilized (Reference 24). Channel-2 T_{BB} values from seven orbits (56, 57, 58, 60, 61, 62, and 63) were composited and analyzed on a 1:20 million map scale using a 58-degree-scan nadir angle limitation. Orbit 59, which was missing, accounts for the gaps over Africa and the central Pacific.

The synoptic analyses were adjusted to approximate orbital times, starting at 0600 GMT and ending at 2000 GMT approximately. The portion of the map lying east of the diagonal running from 20°S , 45°E to 20°N , 90°E consists largely of nighttime data, while the area west of this line consists of daylight recording.

At this time, the Northern Hemisphere is close to its annual heat maximum, the Southern Hemisphere being in midwinter season with its usual strong cyclonic activity extending far northward toward the equator. The darkest gray shading showing the highest temperatures indicates clear to scattered cloud cover (few small cumulus or very transparent cirrus patches). We find

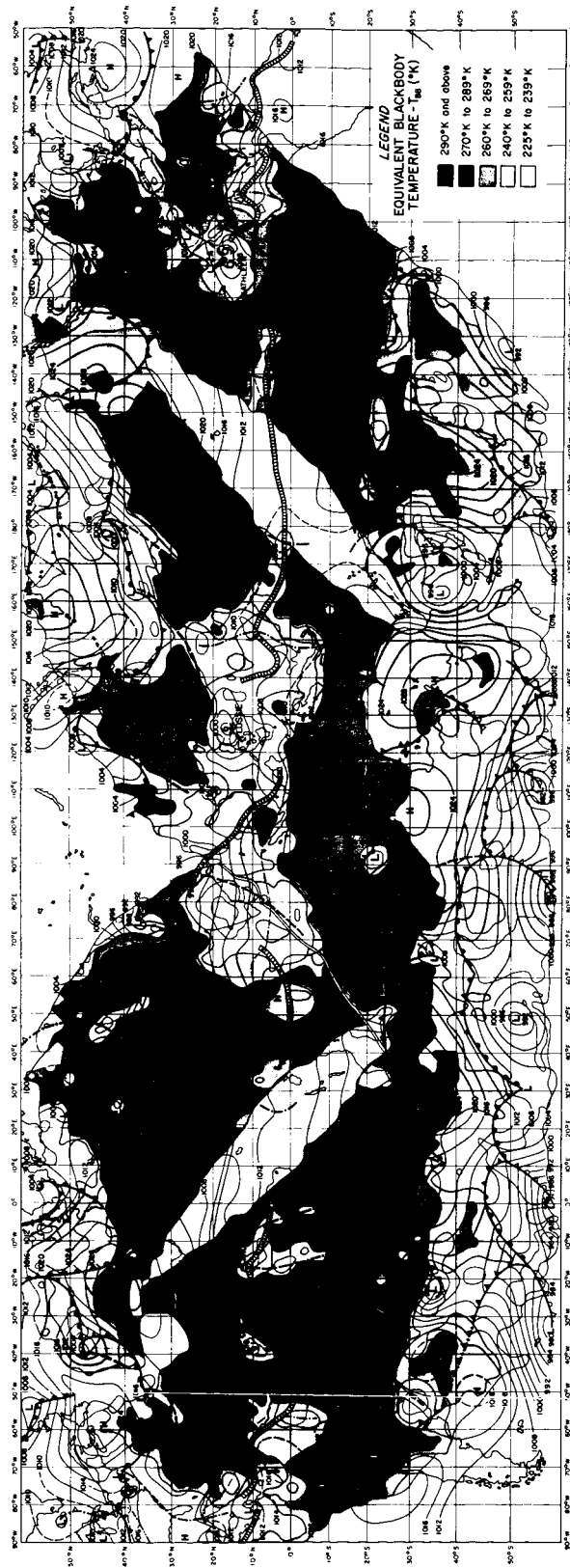


Figure 18.—Composite map of channel 2 radiation data and revised surface synoptic analysis on a quasi-global scale for July 16, 1961.

these T_{BB} values of 290°K —and greater—over the Sahara Desert, Saudi-Arabia, Asia Minor, Iran, Turkmen, Spain, and the deserts of southwest Africa. The semipermanent subtropical highs (T_{BB} values between 270° and 280°K) indicate large areas of clear to scattered clouds.

The lightest gray shading in this figure is associated with the lowest equivalent blackbody temperature ($<240^{\circ}\text{K}$) and, consequently, with the highest amount of high-reaching cloudiness. The areas of high-reaching cloudiness represent the frontal zones of both hemispheres as well as the heavy monsoonal cloudiness over southern Asia and four tropical disturbances. We can distinguish the frontal system over the southeastern United States (see Figures 5 and 8), the polar front over western and central Europe, and a very extended frontal band reaching from Japan northeastward to the Gulf of Alaska. Minimum T_{BB} values, as low as 225°K , indicate that these cloud systems extend upward toward the tropopause. Similar minimum values occur within the cloud mass of the tropical storm "Flossie" over the Philippines. The tropical storms "Kathleen" and "Liza" off the west coast of Mexico are in their decay stage, and T_{BB} values of 230° and greater are indicated. Over the tropical Atlantic Ocean, a singular cloud mass near 10°N and 40°W was identified as the early stage of hurricane "Anna," which was presented in detail in Figure 1.

The cloudiness along the tropical convergence zone is represented by low equivalent blackbody temperature (225° to 260°K) over Central America, northern Brazil, the western African coast, north of Lake Victoria, east of the coast of Somaliland, and between 10°N and the equator over the central Pacific.

The high-reaching clouds over the Indian subcontinent and the adjacent Bay of Bengal and Indian Ocean and southeast Asia clearly show the dense cloud outlines of the southwest monsoon in those regions.

Over the Southern Hemisphere, we can delineate cloud zones of the intensive storm tracks extending northward to Uruguay, close to the southern tip of Africa, and affecting southern Australia and particularly New Zealand.

CONCLUSION

The results of this study indicate that a wealth of synoptic weather information can be derived or measured directly from the conventional TIROS radiation data.

In the future, polar-orbiting earth-oriented meteorological satellites, with their global data coverage and simpler radiometer scanning geometry, will provide an even greater capability for a worldwide real-time synoptic-radiation weather watch, as it was most recently demonstrated by the infrared radiation experiments on Nimbus I (1964 52A) meteorological satellite (Reference 25).

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